SYNTHESIS

By E. SALVATORE

In times of war we usually think of science only as an aid to war. But it is necessary to turn sometimes to thoughts which reach beyond the war and what immediately concerns it. The following article encourages us to do this; for it deals graphically with a particularly important and successful field of modern scientific research.

The author's training has combined both the theory and practice of science. He began his career as a chemist in the capacity of assistant at the University of Naples, held various scientific positions, and finally specialized in the chemistry of cellulose. In this field he has been active in Italy, France, Argentina, Chile, and the Philippines. At present he is a consulting engineer and chemist in Tokyo. He is the author of many articles on scientific and industrial problems and holds a number of industrial patents.—K.M.

PREHISTORIC CHEMISTS

MANY thousands of years ago, perhaps along the coast of Sicily or Africa, men sitting around a fire on a beach observed, on removing the ashes, some hard substance which had not been present on the sand before. This observation would have been without importance if this substance had not been very similar to those used at that time for knives, weapons, and ornaments. The repetition of the phenomenon must have suggested to the ancestors of modern chemists that it was not accidental, and that at high temperatures some correlation existed between ashes and sand. Intentional experiments established the necessary working conditions, and glass was finally produced under technical conditions basically not very different from those in a modern factory. A useful synthesis had been achieved.

Like glass, many other syntheses must have been carried out, especially during the Babylonian, Egyptian, Greek, and Roman civilizations. But the results were all the consequence of occasional observations of facts. Since the dominating aristocracies of those times were interested primarily in art, philosophy and history, technical studies had no academic character and were confined to the activities of the lower classes.

The alchemy of the Middle Ages brought only slight improvement to what had been performed before, since the "theory of transmutation," the "*prima materia*," the "elixir of life," and many of the other products of superstition and pseudoscience, as well as the magician's manipulations required by them, were lacking in any real scientific principle. Only with the announcement of the principle discovered by the brilliant Italian scientist Avogadro and the later establishment of a system of analysis at the beginning of the last century, did synthesis appear as a logical consequence of theoretical study. The principle of Avogadro led to the determination of molecular weights of elements and, indirectly, of atomic weights. Systematic analysis made it possible to look into the constitution of matter.

THE "FORCE OF LIFE"

The synthesis of urea, carried out by the German scientist Wöhler in 1828, reversed one of the most important theories of that time. It was believed that a mysterious force, the "*vis vitalis*," was necessary to produce substances of living bodies, the molecules of which are characterized by an enormous aggregate of atoms of carbon bound together with atoms of hydrogen, nitrogen, oxygen, etc. As this mysterious force was not at the disposal of chemists, matter was divided into inorganic and organic substances, the latter belonging to the vegetable and animal kingdoms. Organic substances could, it was believed, be produced by Nature only. When Wöhler prepared urea from so-called inorganic substances, the difference between organic and inorganic matter began to disappear.

The synthesis of urea was followed by that of many other substances, among them indigo, artificial rubber, pharmaceutical products, etc. Year after year, the number of new products increased and, at present, totals more than 400,000 compounds. As no man, even one endowed with a prodigious memory, could remember all the chemical formulas and the main characteristics of this tremendous amount of compounds, dictionaries like those used for studying languages have been adopted.

A large part of these compounds have never existed in Nature as, for instance, most of the modern dyestuffs and explosives, many products of the heavy-chemical industry, medicinal products such as antipyrine, sulfanilamide, Atebrin, etc., and the *new elements*, of which we shall speak later.

FIVE SYNTHESES

The beginning of the twentieth century is characterized by five principal groups of syntheses: the syntheses of ammonia, petroleum, rubber, resins, and artificial fibers. The astonishing results already achieved are of such importance that the world's economic structure has been greatly affected by them. Of course, these groups of modern syntheses have been made possible only by the countless industrial syntheses developed during the last century, syntheses which no longer evoke our curiosity but without which our modern life, down to the most commonplace object, can hardly be imagined.

But to return to ammonia: there are two fields of human activity that require large quantities of nitrogen—war and agriculture. Before the Great War, the manufacturers of explosives obtained their nitrates from Chile, while agriculture had to rely on organic manure for the replacement of nitrogen in the soil. The exigencies of the last war forced German scientists to develop the process of obtaining nitrogen from the air. War necessity made it possible to build the costly plants and provide the vast energy required for this process. A secondary, but perhaps far more important result, was that agriculture now possesses an added, abundant source of nitrogen.

Much has been said and written in recent years about synthetic petroleum and rubber. We only wish to point out that, in contrast to the huge coal reserves of the world, the known resources of petroleum are, at the rate of prewar consumption, enough for fifty years only. In some of the modern processes of petroleum synthesis, even the most inferior grades of lignite can be utilized.

The significance of the discovery of synthetic resins in the present century has perhaps not as yet been fully realized, possibly because these materials are still considered as substitutes or imitations of ivory, horn, mother-of-pearl, ebony, etc. However, these products have long passed the stage of imitation and are entirely new compounds with special properties. They have found use in all provinces of our modern life, changing our traditions, habits, and standards of life. An innumerable quantity of machine parts has already been produced from them; and in some cases the solution of technical or mechanical problems could probably not have been achieved without these special new synthetics.

In the case of synthetic fibers, the earliest production, known as "artificial silk," justly held the stigma of imitation, substitution, or adulteration. Gradually, however, as the properties of artificial fibers were improved, they were found very suitable for many purposes, and their use increased. The list of raw materials from which rayon, staple fiber, and artificial wool are produced includes cellulose, linters, casein and, more recently, coal. Although the great mass of fibers still comes from raw materials known to our ancestors, the sale of rayon, "Nylon," "elastic glass," and similar articles is steadily on the increase. At present, the trend is toward reducing as much as possible the diameter of the basic filaments. In this way, a fiber should finally be obtained which is finer than silk or wool and consequently materials which will be lighter, more insulating, and softer than any textiles known at present.

WAR AND PROGRESS

The war, which is upheaving the world, has not only tremendously increased the output of the chemical industry in every country but has probably developed and enlarged new syntheses for producing those raw materials which, owing to blockades and other difficulties in transportation, cannot now be obtained from their old sources, or new materials useful in the conduct of war. Chemistry is now playing one of the most important roles, and the outcome of the war is very much dependent on the development of the chemical industry. In the present circumstances, modern research and industrial development are being kept as secret as possible. But whatever the character of the chemical development in every country may be, we may hope that, in spite of all the suffering the war will still bring and leave behind, chemical studies and their industrial application will alleviate our lives after the end of the war.

We know, for instance, that many products could not have been produced synthetically in normal times on account of the tremendous cost of the necessary machinery and the difficulties involved in the chemical processes. As such drawbacks must be overcome in war time, the postwar period will be able, under exceptional economic conditions, to utilize new plants and all the experience gained during the war. Even for certain specific products used only in war, there is always the possibility of their being used in peace time, as was the case after the last war. An example of this is phosgene, that very poisonous gas employed in the last war. It seemed at that time as if it would never be used again, whereas actually, on account of the ease with which it can now be produced economically, this gas has been employed since the last war in many industrial syntheses.

RADIOACTIVE ELEMENTS

We know since the beginning of this century that from the spontaneous disintegration of radioactive elements, during which alpha and beta particles are discharged, new series of elements are generated in which each element transforms itself into another, this again into others, and so on until a stable element is reached whose chemical properties are identical with those of lead but whose atomic weight differs slightly from that of common lead. The loss of alpha particles entails a decrease of the atomic weight, whereas the chemical properties of the element remain the same. On the other hand, the loss of beta particles does not cause a change of weight, but the chemical properties of the new element are affected. (For simplicity's sake we shall ignore the gamma particles.)

Among these series of radioactive elements, that of uranium is the most important. From uranium, through the loss of alpha and beta particles, radium is formed which, by further disintegration, forms G-radium, whose atomic weight is 206, but whose chemical properties are identical with those of lead, the atomic weight of which is 207.22. In this way we have passed from the radioactive element uranium to another which is no longer radioactive and which has been identified with common lead, except with regard to its atomic weight.

THE ISOTOPES

The fact that *two* elements "lead," with identical chemical properties but different atomic weights, could exist, was a surprise, since our conception of an element is that it consists of a material with a definite and absolutely constant weight. This extraordinary discovery led to the supposition that other elements might also be composed of a mixture of different elements having equal chemical properties but different atomic weights, and experience has confirmed this. We know now that neon, whose atomic weight is 20.2, consists of three elements whose atomic weights are 20, 21, and 22. Chlorine, with an atomic weight of 35.46, consists of two elements whose atomic weights are 35 and 37 respectively. The former represents 70 per cent of the total. Tin (atomic weight 118.70) is formed by ten elements, whose atomic weights go from 112 to 124. Oxygen is formed by three elements whose atomic weights are 16, 17, and 18 respectively. And hydrogen, the atomic weight of which is 1.0078, consists of three elements whose atomic weights are 1, 2, and 3. The first of these represents 99.8 per cent of the total, the second 0.02 per cent, and the last only 0.00000001 per cent.

Elements with similar chemical properties but different atomic weights have been called "isotopes." The discovery of isotopes and of the possibility of separating them from each other allows us to change the character of some existing compounds. For instance, from the isotope of hydrogen, having an atomic weight of 2 (normal hydrogen has 1), scientists have prepared many compounds in their laboratories, such as heavy water, heavy ammoniac, heavy methane, and heavy benzol. The case of heavy water is, from a scientific point of view, especially interesting on account of water being the principal constituent of organic tissues. Its partial or total substitution by heavy water in living organisms has a noticeable effect on the phenomenon of life.

HEAVY WATER

The chemical formula of water is H_2O. This means that the molecule of water consists of 2 atoms of hydrogen and one atom of oxygen. In heavy water, normal hydrogen has been substituted by heavy hydrogen. The new water is therefore heavier than normal water. The different characteristics of normal and heavy water are as follows :

Characteristics	Normal Water	Heavy Water
Density 4°C	1.0000	1.1066
Boiling Point	100°.00	101°.42
Melting Point	0°.00	3°.8
Temperature of highest density	4°	11°.6
Salt solubility in 100 parts	35.9 gr.	30.5 gr.

Heavy water is always contained in normal water, including sea water, to the extent of 0.002 per cent. It follows that in living organisms and in our own bodies heavy water must also be present in the same percentage. We do not know as yet what the effect of a total or partial substitution of normal water by heavy water in living organisms would be. At any rate, as it has been found that the activity of reaction differs greatly for these two types of water, it seems logical to suppose that life must be affected by this different activity. Biological research will solve this problem in the future.

If, in addition, we assume the substitution of the normal oxygen of heavy water by its isotope with the atomic weight 18 (the atomic weight of normal oxygen is 16), what would the nature of such still heavier water be? And what would be its effects on living organisms? Perhaps we shall be able to obtain more resistant organisms, or more active, or longer living ones, characterized by some special qualities which we cannot yet visualize. The life of plants and even of animals may assume a new aspect.

As a result of the most recent research regarding matter, we have found that a new world is looming all around us, a new world which appears no less incomprehensible to our imagination than that which once surrounded primitive man.

PRODUCING NEW ELEMENTS

Until a few years ago it was believed that radioactivity and the disintegration of the atom were spontaneous phenomena that man could not provoke. In other words, it seemed certain that man could not transform one element into another. But recent discoveries have shown that it is possible artificially to induce radioactivity in elements which formerly were considered inert or which had no radiating properties. Moreover, it has also become possible to disintegrate atoms and consequently to transform one element into another known element or into a new one not yet listed among the known elements which consitute matter. This means, in a way, that man has already produced *new matter*, even though so far this has been done only in very small quantities.

Radio-sodium has been produced, whose radioactivity in regard to emanation of gamma rays is double that of radium. This new material is at present being carefully examined in order to make use of it in therapeutical applications. The element beryllium has been transformed into nitrogen, and that again into carbon. Aluminum has been transformed into phosphorus, and that again into silicon. New elements have been produced, such as the element ekarhenium and three others, the atomic weights of which are equal to those of the already known osmium, iridium, and platinum. Studies, discoveries, and syntheses have been actively carried out, leading to the conclusion that every element except hydrogen can be transformed into another known element or into a new one which has never existed before. Thus it is very probable that the new elements can give rise to a new series of elements different from those already produced, and so on. In order to understand how this work has been accomplished, we must consider the constitution of the atom.

According to Bohr, we may imagine the atom as a solar system in which a central nucleus represents the sun and electrons are the planets. The nucleus must be considered as a material mass which is always a multiple of that of the nucleus of hydrogen, while the electrons consist of electric charges only. As in other solar systems, the electrons incessantly rotate around the central nucleus on elliptical orbits which are defined by the speed of the electrons and by the attractions of the system.

Except in radioactive elements, all particles constituting the nucleus, as well as the whole atom, are in perfect and constant equilibrium by means of forces the immensity of which is far beyond our imagination. But when some cause disturbs this equilibrium, one or more of the above-mentioned particles are thrown out into space. The energy liberated thereby is greater, in comparison, than that of the biggest projectiles used in war. These atomic projectiles have been used for disintegrating the atoms of elements, for transforming them into others, or for producing new elements.

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It has been said that Nature must have been a very skillful architect to have built up the immense universe surrounding us with the few objects which we call elements. But of late we have learned to carry out on a minute scale some of the work as that accomplished by Nature. Of course, in doing this we use the same energy as that which accompanies matter, which matter, according to modern theories, does not differ in its essence from energy. Indeed, nowadays there is no theoretical difference between these expressions.

Recent discoveries have opened a window onto a new world, a world completely different from the one we knew a few years ago. Generally speaking, we were accustomed to consider the terms "world" and "matter" as one and the same. But "matter" no longer has the same meaning as before, nor, as a consequence, has "world." In trying to clarify the ideas of matter and energy, we found that matter and energy are one and the same.

It is impossible to say where the latest discoveries may lead man. But we can surmise extraordinary possibilities. For we know, not only that we can transform matter, as alchemists dreamed of doing, but also that we have begun to produce new matter.